NGST High Dynamic Range Phase Estimation

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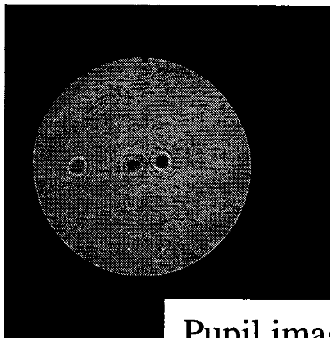
Outline

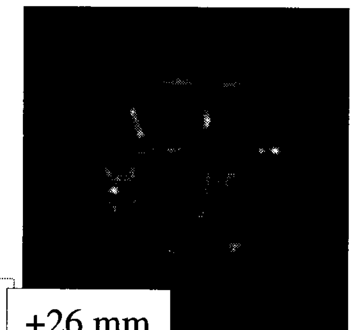
- Review of unwrapping & ordinary phase retrieval:
  Phase Retrieval as Model Error Estimation
- Outline of Iterative Hybrid Retrieval Algorithm
- Unwrapping
- Retrieval of HDR (High Dynamic Range) Testbed Data
- Current Status

Typical Focus-Diverse Phase Retrieval Data Flow

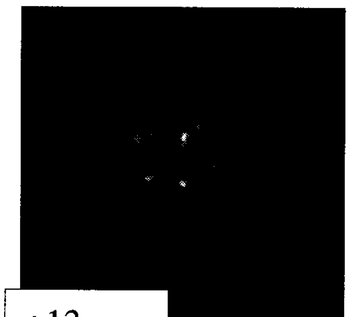


Pupil image

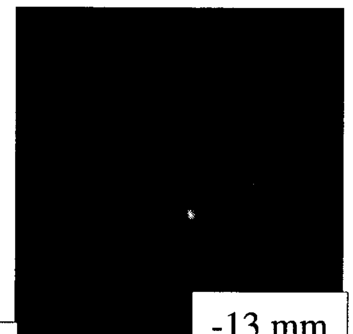
The modified Gerchberg-Saxton algorithm uses measurements of the pupil intensity distribution as well as focal planes images with known defocus.



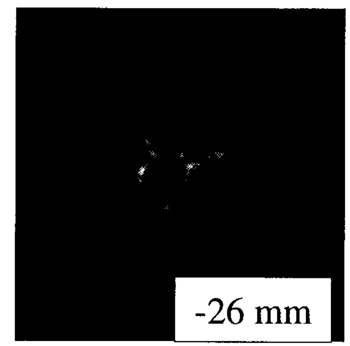
+26 mm



+13 mm



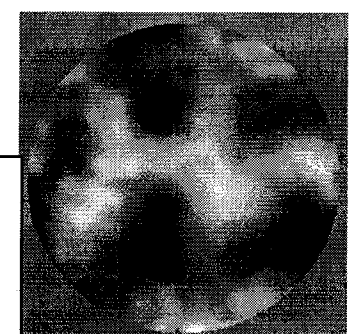
-13 mm



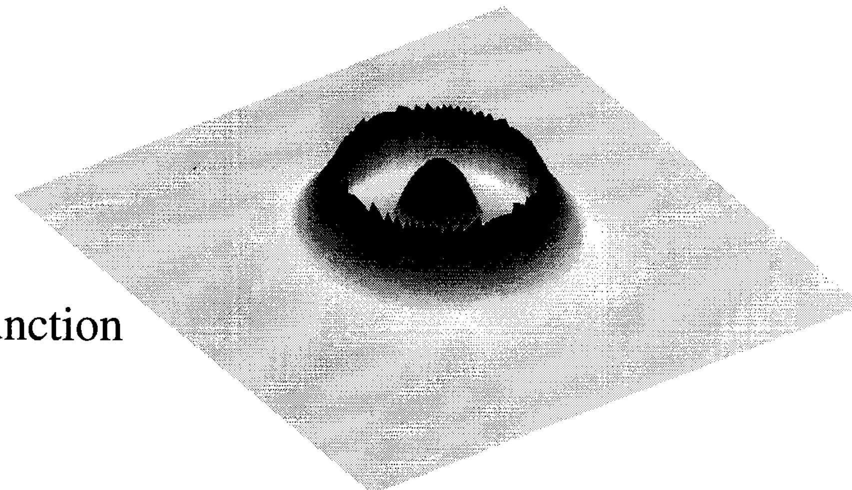
-26 mm

known defocus

The algorithm estimates the pupil phase (here injected with one of the two testbed DMs):



Phase Wrapping



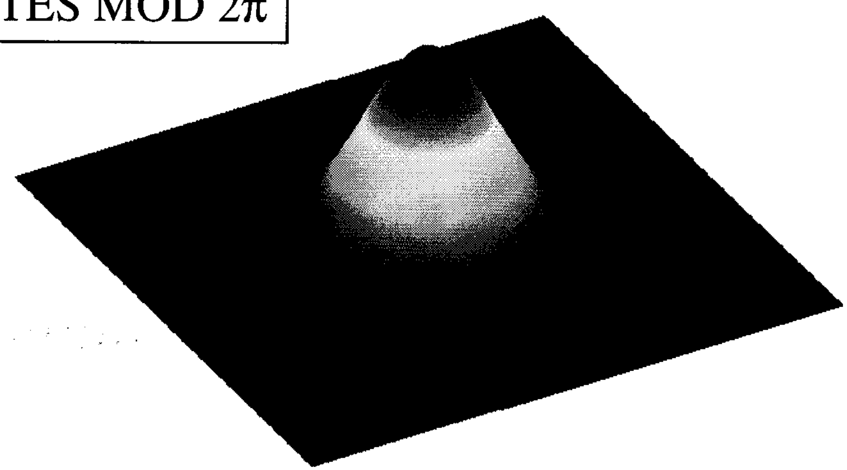
Wrapped influence function

↑

PHASE RETRIEVAL OPERATES MOD 2π

↑

True phase surface



Phase unwrapping as a postprocessor of estimated data

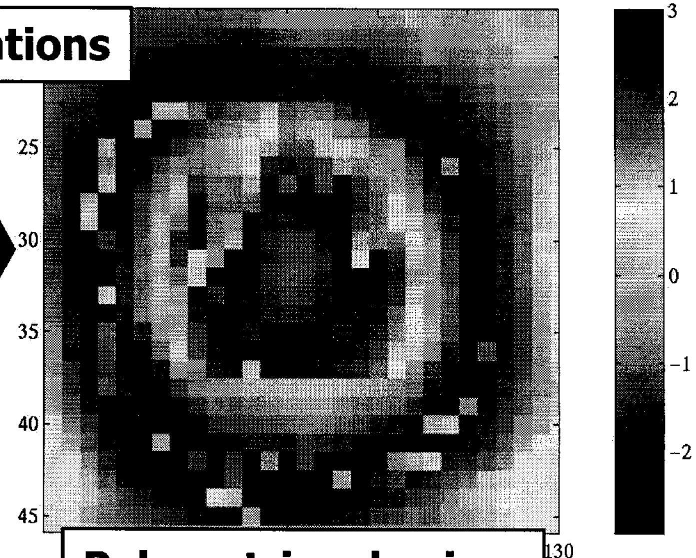
Crisp wrap boundaries appear as baseline phase retrieval converges. Slow for HDR data.

Measurement & Model

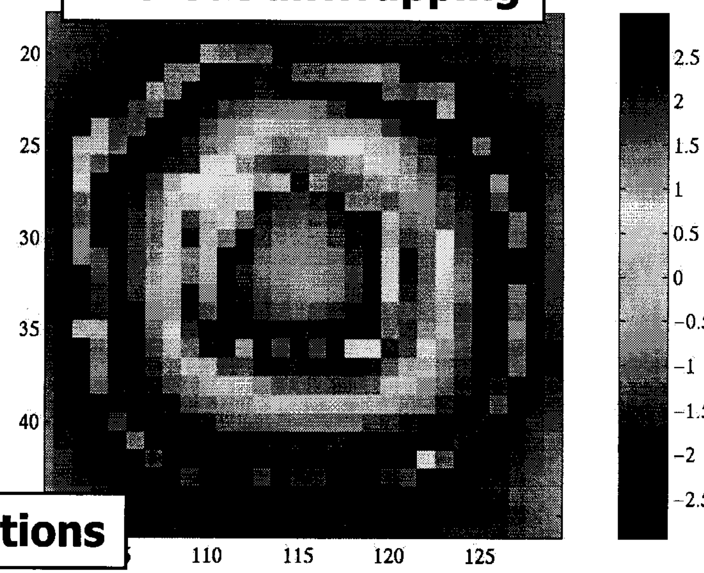
Baseline Focus-Diverse MGS Algorithm

Unwrap

after 30 iterations

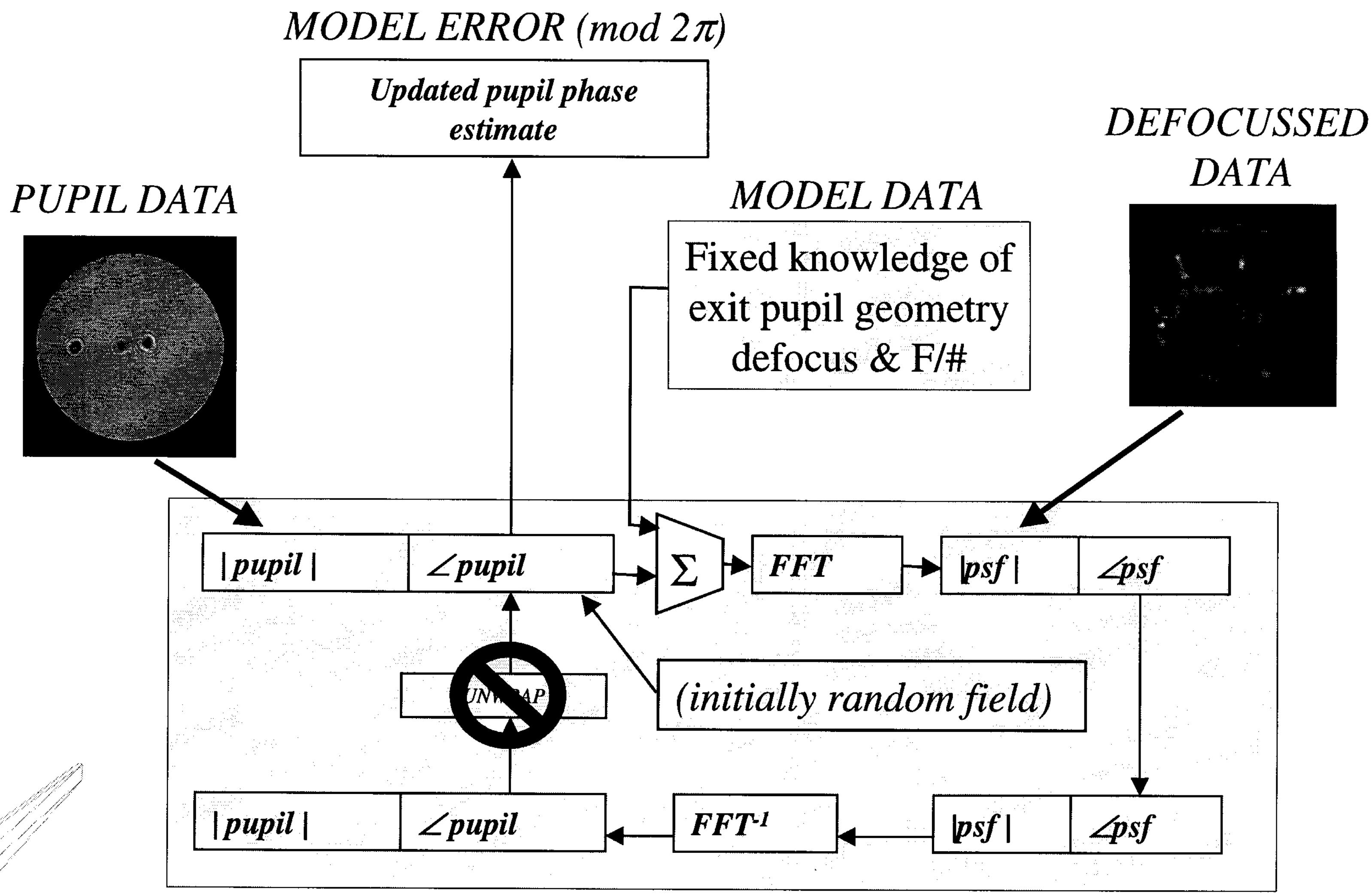


Poke retrieval using baseline algorithm without unwrapping

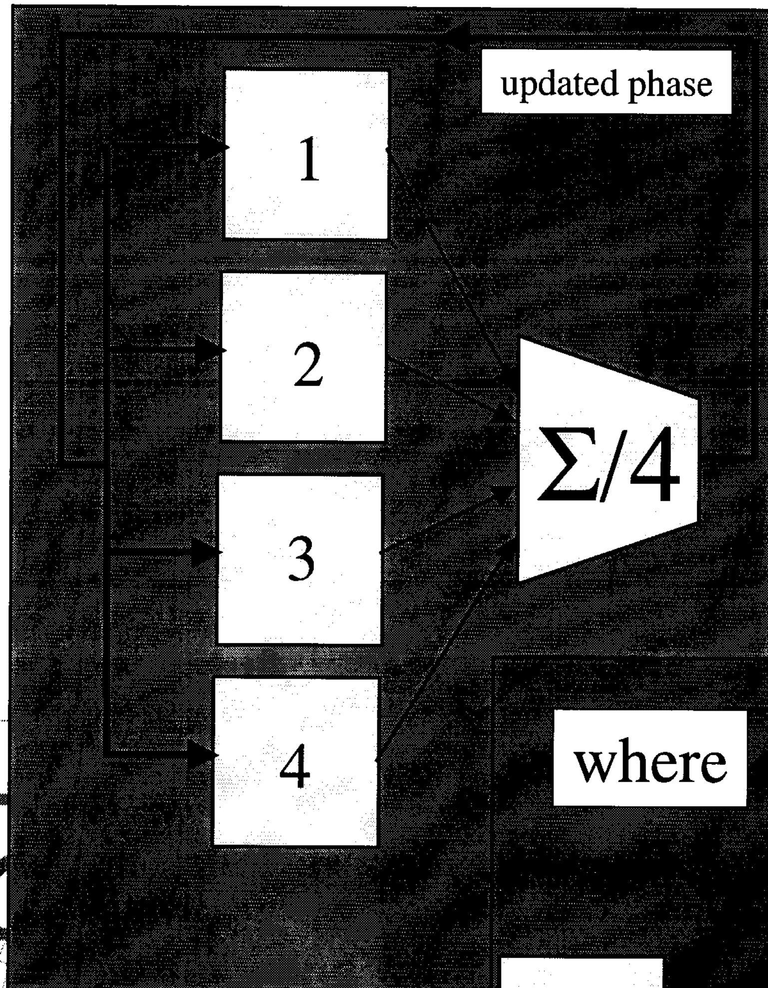


after 85 iterations

The MGS Algorithm As an Error Estimator



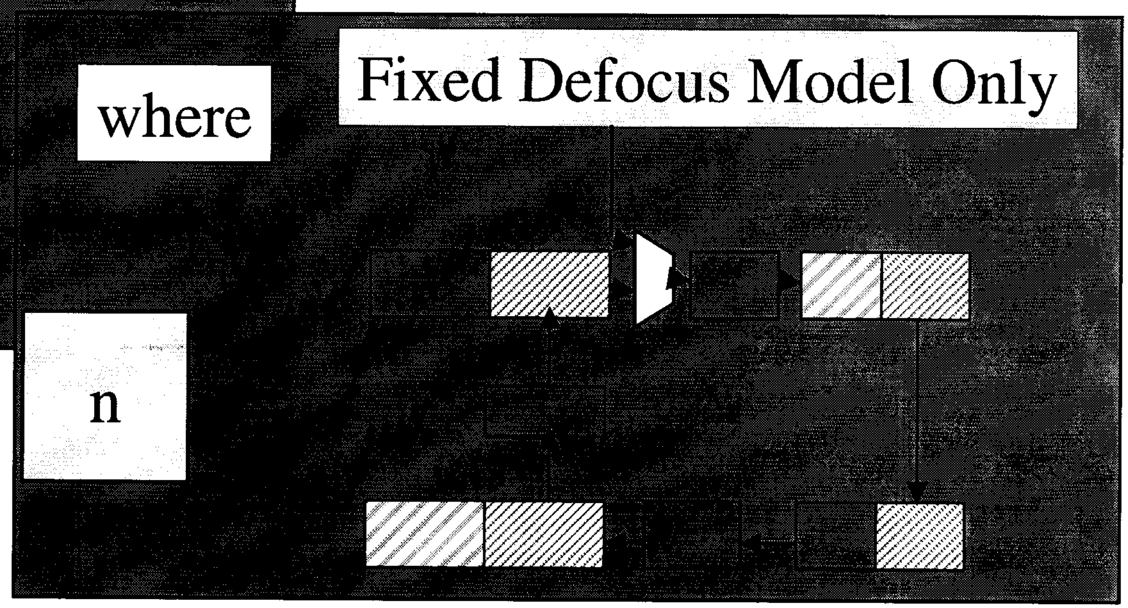
Baseline Focus-Diverse MGS Error Estimation



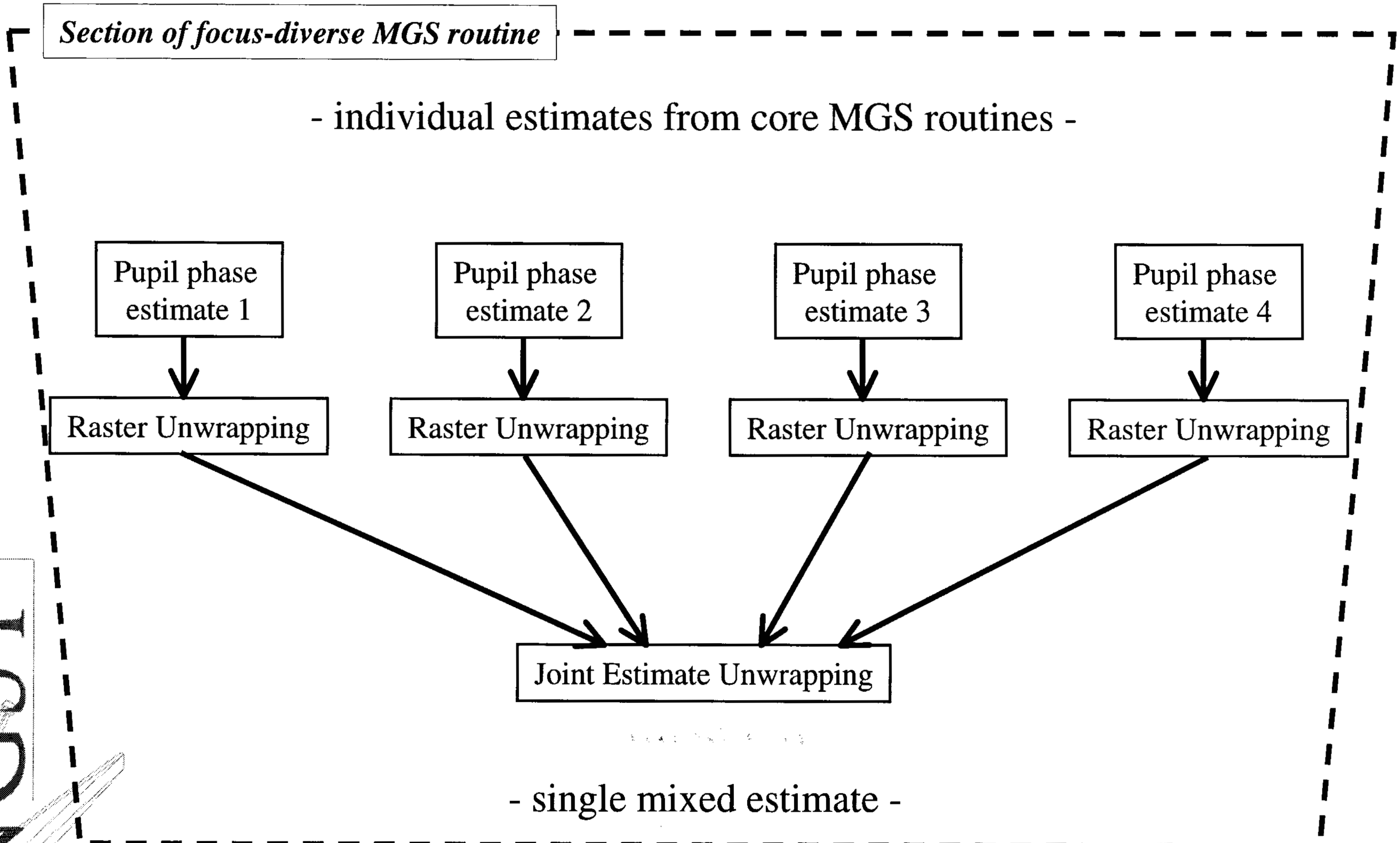
Independent MGS estimation of the error (ie deviation from defocus). in 4 respective models

By averaging the 4 estimates and restarting the MGS routines from the prior estimate, we polish the resulting error estimate.

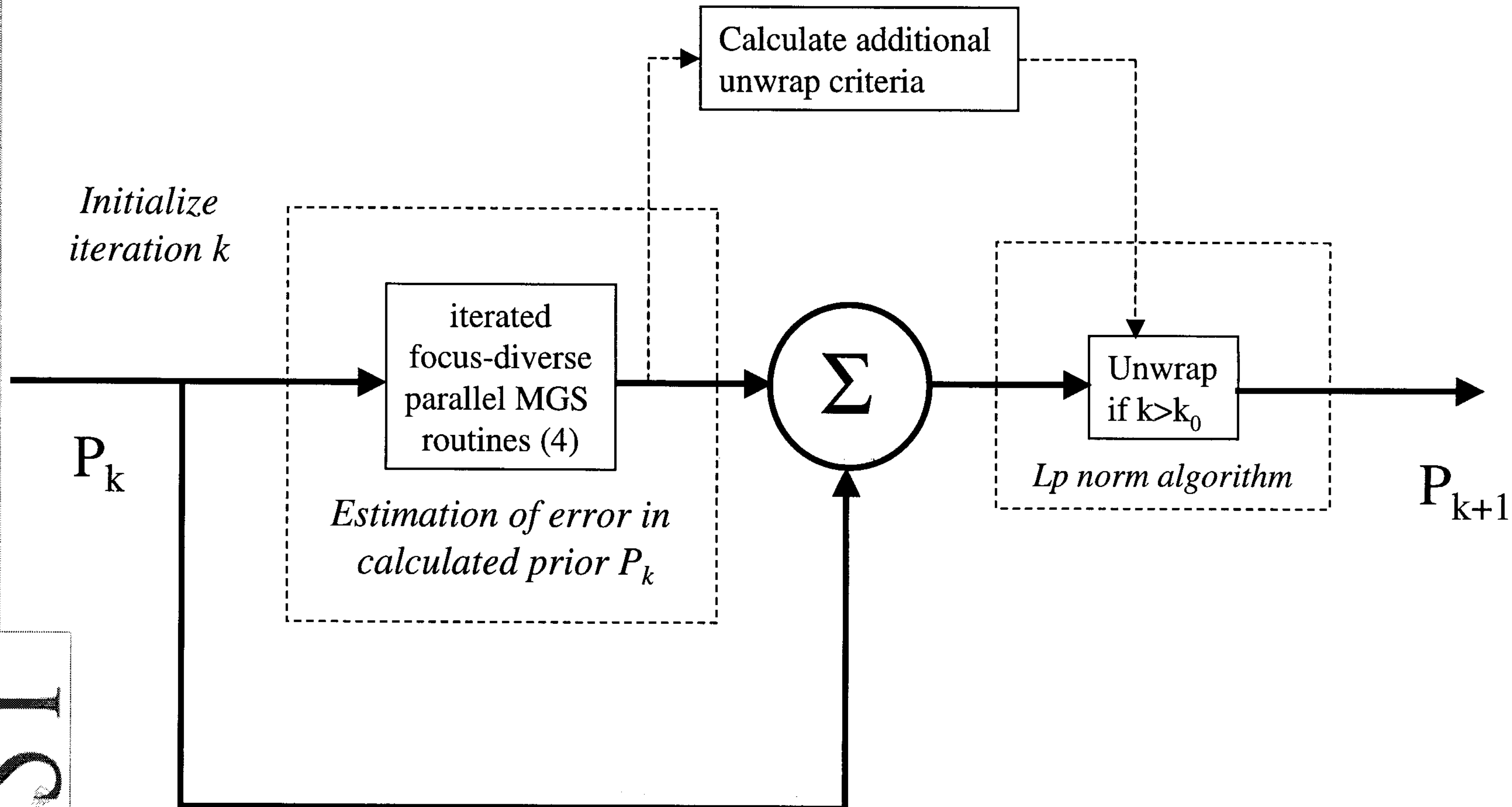
(Normally, joint unwrapping is implemented at this level. However, it is replaced by an alternate technique for higher dynamic range.)



Ordinary WCT Phase Unwrapping

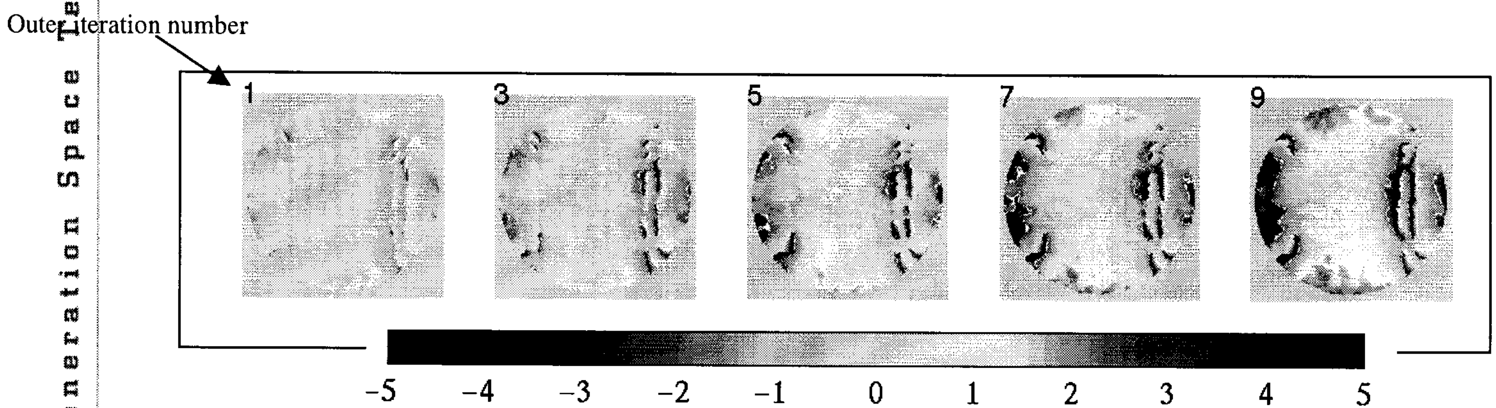


HDR Algorithm

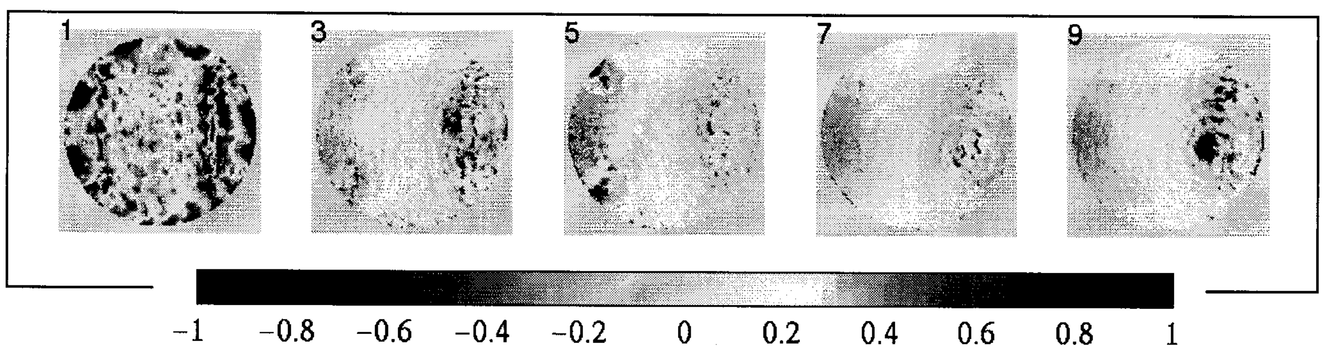


One "outer-outer" iteration on k^{th} pupil estimate P_k

Case #1: Low Order Zernike part 1: prior to first unwrap



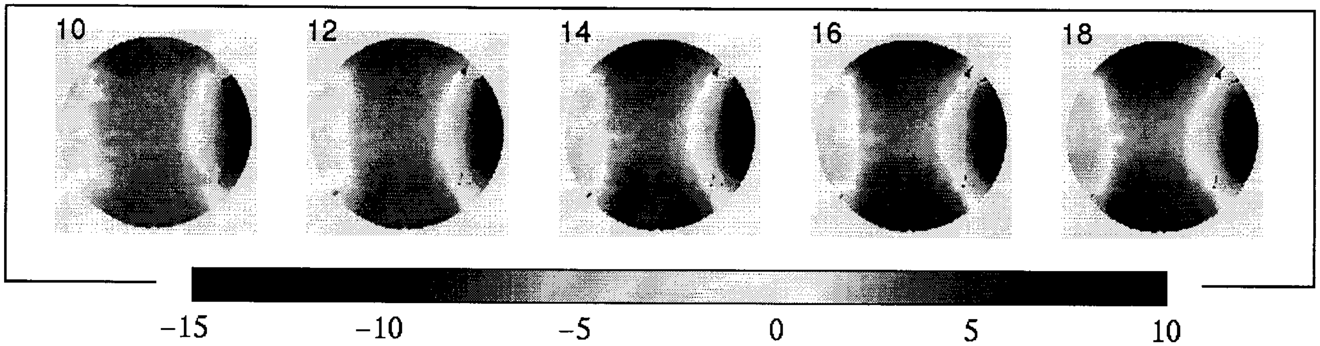
Exit pupil phase estimate



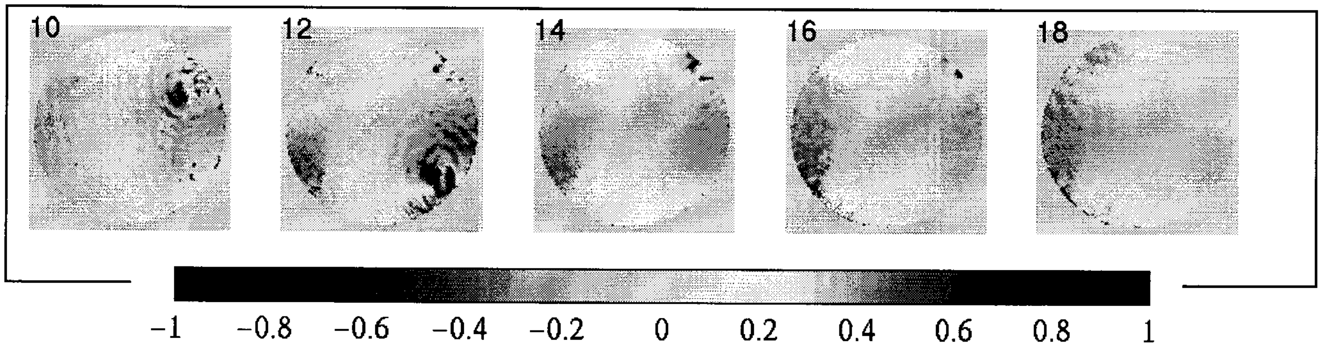
Calculated model error

Note the poor quality of phase estimates, and the correspondingly high amplitude of the error terms that are used to additively update this estimate prior to the next iteration. Prior to unwrapping, the error term refines the phase wrap boundaries in the estimate.

Case #1: Low Order Zernike
part 2: after first unwrap



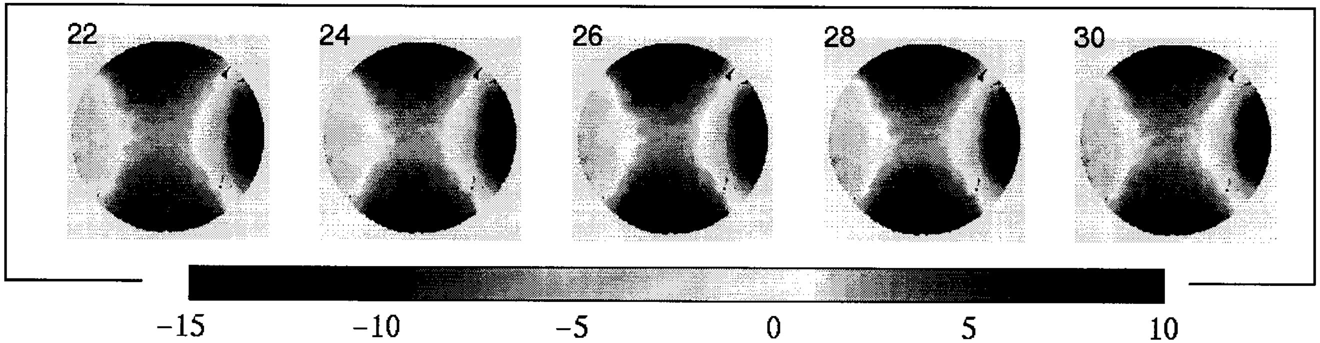
Exit pupil phase estimate



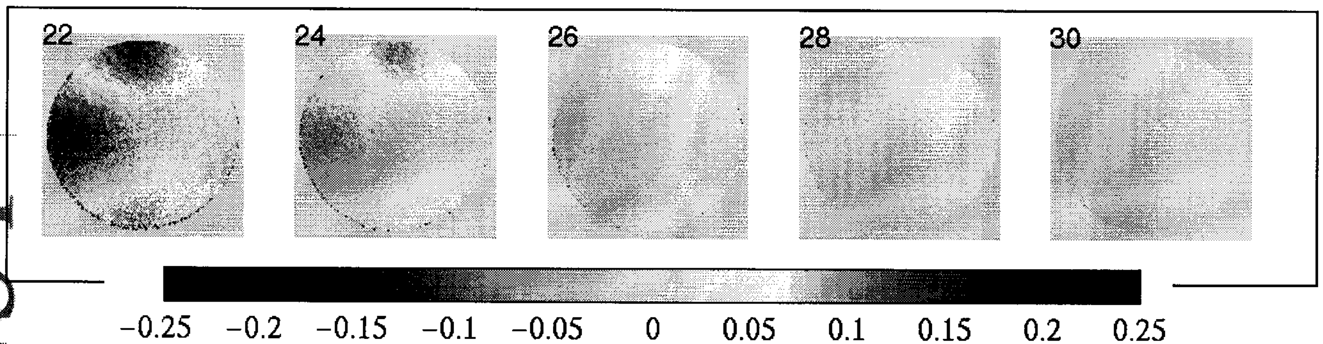
Calculated model error

After the first unwrap at iteration 10, the aberration is qualitatively apparent. With successive iterations, the feedback term becomes small and contains only low spatial frequency components.

Case #1: Low Order Zernike part 3: additional refinement



Exit pupil phase estimate

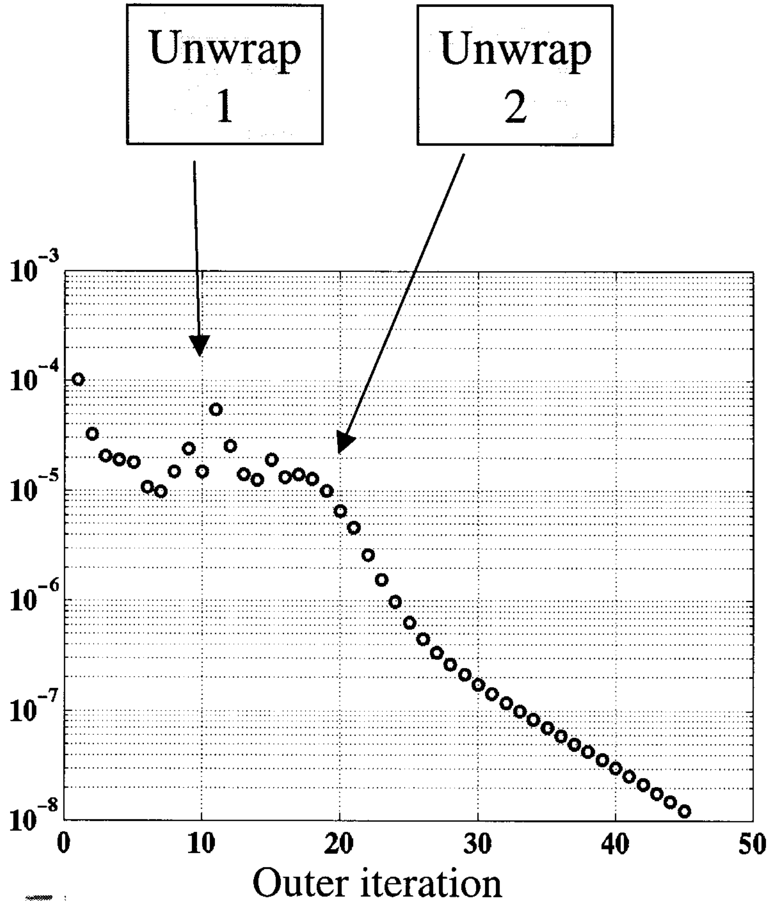


Calculated model error

4.14 waves (wavefront)

Additional iterations reduce the feedback term to very small values.
Note the changes in colormap scale from part 1 to part 3.

Convergence of Case #1



If the error estimate term at iteration i is the matrix A^i then we may characterize the convergence of the algorithm by the scalar quantity

$$\chi^2_{i,j} = \sum_{m,n} A^j_{m,n} - A^i_{m,n}$$

The results for Case #1 are plotted on a semilog scale to the left. Note that the units for this plot are in square optical path difference (OPD) which is proportional to phase

$$OPD = \frac{2\pi}{\lambda}\phi$$

Here the wavelength is 0.6328 ? m.

Currently, when this benchmark falls below a threshold, unwrapping is stopped.

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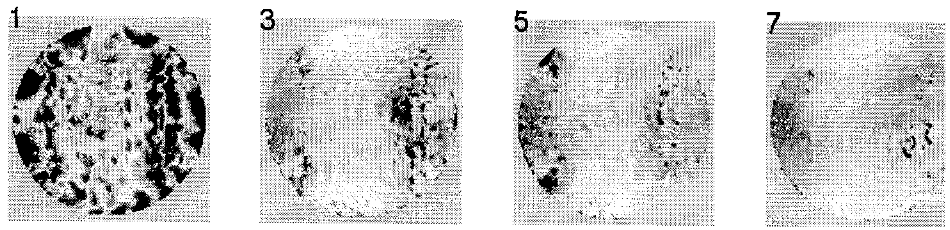
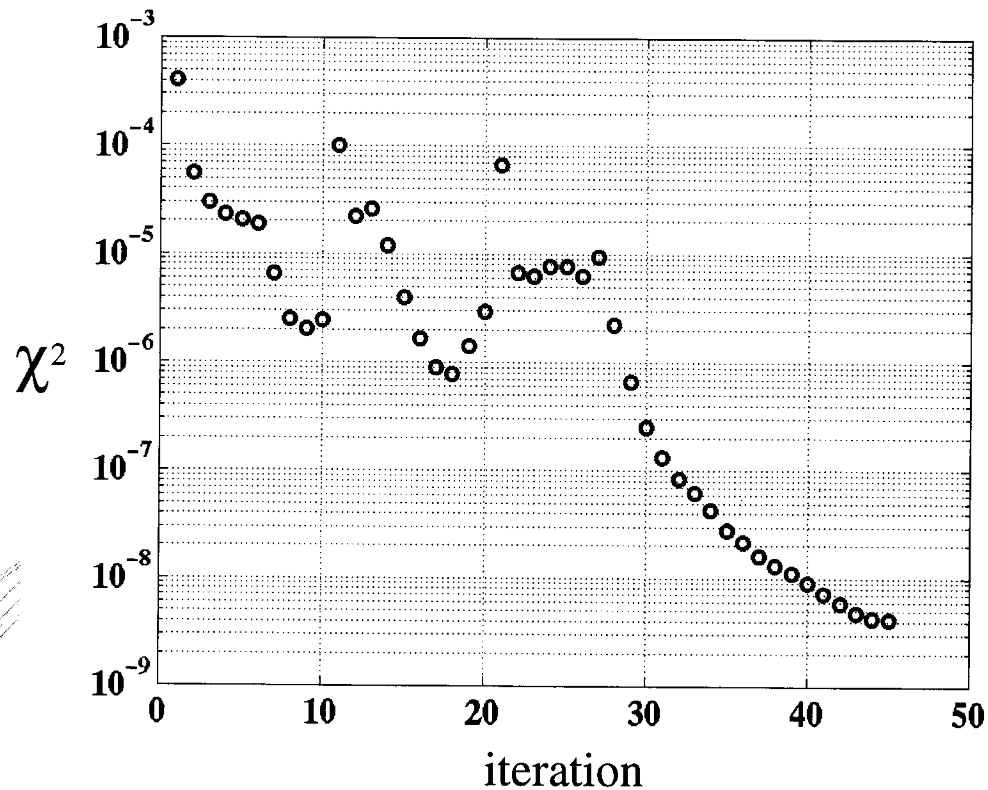
Convergence & Unwrap Criterion

χ^2 derived from MGS-calculated error terms:

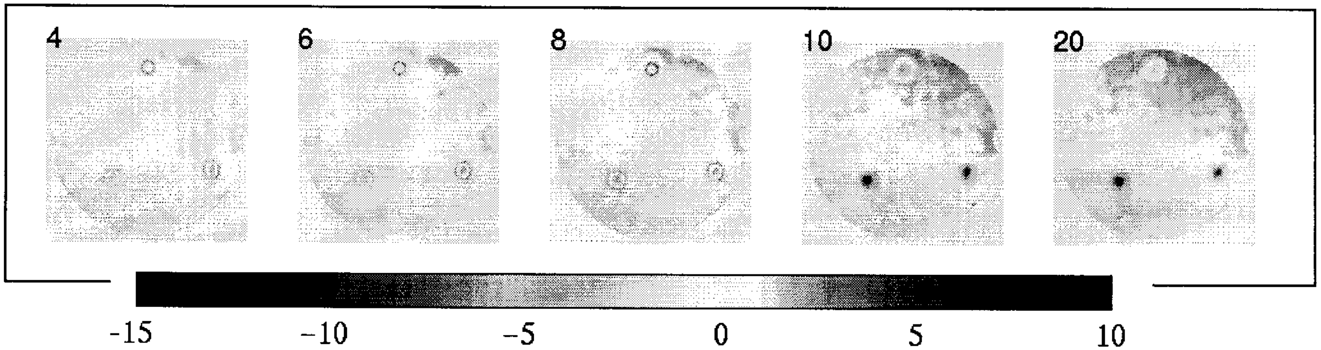




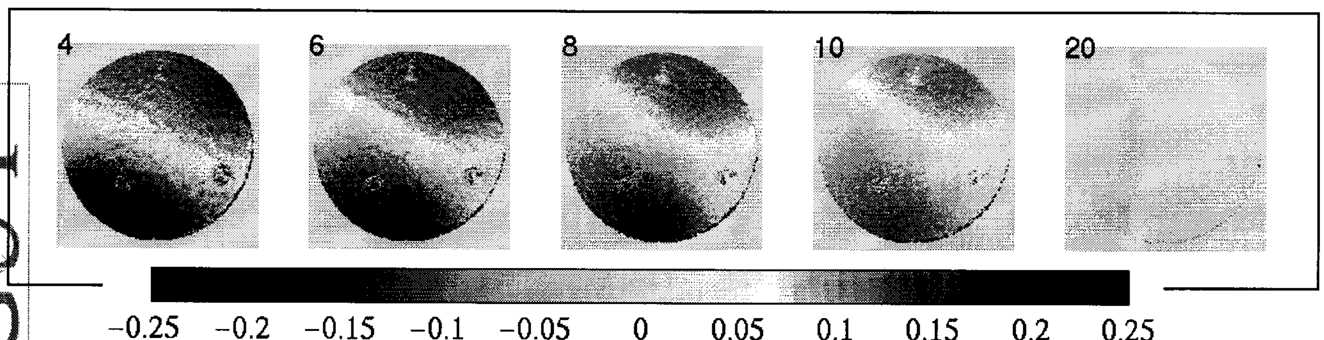
Unwrap every 10 iterations
if
χ^2 > threshhold

χ^2 = variance of adjacent error estimates

Case #2: 0.45 μm Actuator Poke



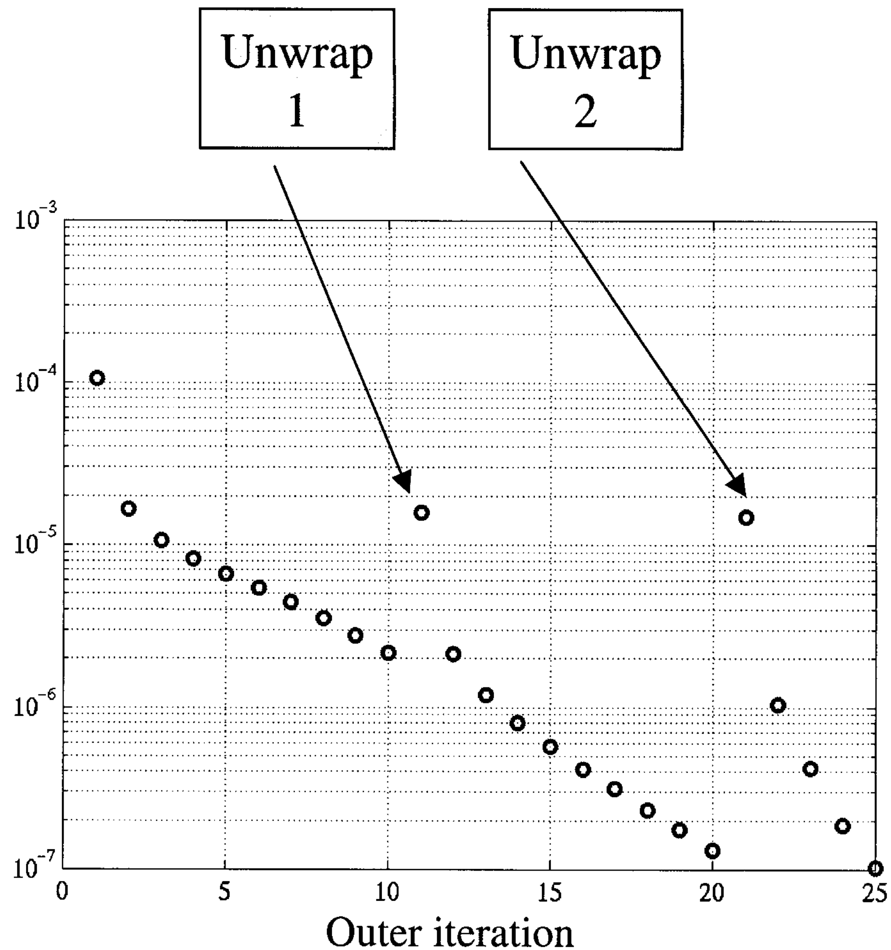
Exit pupil phase estimate



Calculated model error

Individual actuators set at 0.45, 0.45, & 0.30 μm

Convergence of Case #2: Actuator Pokes



Current Platform

• The coarse-grained nature of the joint MGS algorithm lends itself particularly well to a small cluster of PCs connected to form a Linux Beowulf(1).

• Each pupil image/defocus image core calculation runs on a single processor. Inter-process synchronization and communication are managed using the MPICH parallel libraries.

• Disk memory containing constant data is shared between processors.

• The major data element shared via the Beowulf TCP/IP network is the evolving pupil phase estimate. 228x228*8 bytes interchanged every 10 seconds.

Hardware Specs
- 4 x 800 MHz AMD Athlon COTS PC boxes
- 256 MB local RAM each
- 100BASE-T coupling via local switch

Software
- data directory shared via NFS
- Linux 2.4 kernel
- Fujitsu Fortran compiler
- MPICH library
- total cost: roughly $7k plus commercial s/w

JPL

Next Generation Space Telescope

NGST

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SUMMARY

NGST

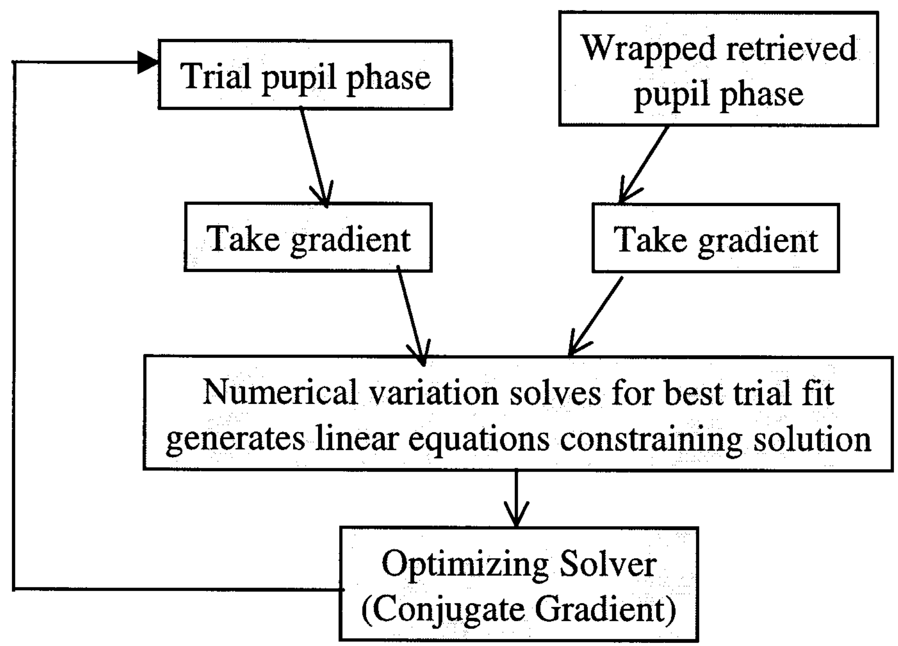
- The WCT-1 testbed hase been used to investigate retrieval of unwrapped pupil phase from high amplitude DM settings.

- Higher dynamic range data requires more iterations for convergence that supports crisp unwrapping boundaries.

- The current algorithm uses partially unwrapped data to successively update the model.

- Smooth exit pupils with a few waves of phase can be retrieved. Cases tested include low order Zernikes, random phase distributions, and single actuator pokes.

Unwrapping Algorithm of Ghiglia & Pritt: Overview



This algorithm tends to produce smooth results useful as intermediate steps in the mode updating loop.